Determinants of Renewable Energy Deployment – Evidence for Developing Countries 1980–2008

Draft

Birte Pohl (GIGA),
Michael Jakob (PIK), Steffen Schlömer (PIK)

Motivation & Research Question

- What are the drivers and barriers to RET uptake in the power sector of developing countries?

- Why is this important?
  - Power sector accounts for 41% of global CO2 emissions
  - Growth of emissions in recent years can almost exclusively be attributed to developing countries
  - Likely to grow further with economic development progressing
  - RETs are a key mitigation technology and have multiple public co-benefits
  - Developers mostly sit in industrialized countries -> cross-country diffusion required

Theoretical Background (1/2)

- Many studies of cross-country technology diffusion
  - Focused on „success stories“, i.e. technologies that been widely diffused and caused „global change“
  - Grounded in „new growth theory“, where technological innovation is the engine of growth
  - Strong focus technology supply side (openness and IPRs)
  - „Lately“, more focus on demand side (absorptive capacity, appropriate technologies, local attractiveness, capability to adopt)

- Several key determinants identified:
  - Openess to trade and FDI
  - Distance between source and recipient
  - Labour turnover
  - Human capital
  - Domestic R&D investments
  - Sectoral specialization
  - Deployment of predecessor technologies
  - Governance

Theoretical Background (2/2)

- RETs likely differ from conventional „success stories“
- Attractiveness derives to considerable degree from „positive externalities“ and related institutions
  - Climate change mitigation (reduced GHG emissions)
  - Improved public health (reduced local air pollution)
  - Increased energy security (reduced fossil fuel imports)
  - Improved energy access (decentralized production)
- Finance considered as further key determinant in DCs
- Other sector-specifics and factor endowments relevant

Most Closely Related Literature

Brunnschweiler (2010)

- examines the role of financial sector development for RET adoption
- 119 non-OECD countries, 1980-2006
- finds that financial development has a significant positive effect on RET and non-hydropower renewables

Popp et al. (2011)

- examines the effect of RET-specific knowledge on deployment
- 26 OECD countries, 1991-2004
- finds a small but significant positive effect

Econometric Model

First model: per capita electricity generation from RET (hydro and non-hydropower) in 1000 kWh per capita in country *j* in year *t*

$$\log(\mathrm{RETPC}_{jt}) = \beta_0 + \beta_1 \log(\mathrm{X}_{jt}) + \beta_2 \mathrm{D}_{jt} + \mathrm{u}_{jt} \quad (1)$$

Second model: per capita electricity generation from non-hydropower (geothermal, wind, solar, tide and wave, biomass and waste) in 1000 kWh per capita in country *j* in year *t*

$$\log(\mathrm{NHPC}_{jt}) = \beta_0 + \beta_1 \log(\mathrm{X}_{jt}) + \beta_2 \mathrm{D}_{jt} + \mathrm{u}_{jt} \quad (2)$$

Table 1: Summary of RET Electricity Generation, 1980-2008

Variable	Obs	Mean	Std. Dev.	Min	Max
RETPC	4004	0.32	0.82	0.00	10.35
NHPC	4004	0.01	0.03	0.00	0.35

Data Source: EIA, share

Control Variables I

- Commonly discussed drivers of technology adoption
  - level of economic development (log of GDP per capita)
  - openness (trade, FDI)
  - human capital endowments (enrollment rate, completion rate)
  - level of financial development (assets, liabilities, credit)
- Environmental externalities and related regulatory institutions associated with RET
  - feed-in tariff
  - quality of the environmental regulatory system (regulation, 4 quartiles)
  - local pollution (pm10, 4 quartiles)

Control Variables II

Table 2: Summary Statistics of Control Variables, 1980–2008

Variable	Obs	Mean	Std. Dev.	Min	Max
gdppc	3362	3956.66	3446.76	150.81	20098.27
trade	3366	76.80	41.52	0.31	375.38
fdi	3218	3.15	6.29	-82.89	90.74
enrollment rate	3014	95.78	25.39	13.77	232.84
completion rate	2041	72.37	27.58	0.00	150.36
assets	3098	73.17	23.10	1.73	126.45
liabilities	2571	24.36	20.67	0.11	165.96
credit	2572	37.91	24.71	0.19	148.94
feed-in tariff	4234	0.02	0.14	0.00	1.00
regulation	1160	-0.69	0.52	-1.74	0.18
PM10	2397	66.40	46.16	5.56	480.56

Econometric Methodology

- Random Effects (RE) and Fixed Effecs (FE) estimation
- RE: assumption that the unobserved effect is purely random and uncorrelated with the explanatory variables
- FE: accounts for unobserved heterogeneity across countries, requires the assumption of strict exogeneity to hold
- hausman test (Hausman 1978) to test whether the country-specific effects are uncorrelated with the regressors (appropriateness of the RE model)

➔ Our analysis shows that in some specifications RE is consistent and efficient, while in others not. In this case, the FE results should be preferred.

Results I: Openness to Trade and FDI

RET

	RET1 FE coef/t	RET1 RE coef/t	RET2 FE coef/t	RET2 RE coef/t
gdppc	0.583***	0.610***	0.631***	0.643***
	(11.568)	(14.103)	(12.170)	(14.514)
fdi	0.011	0.023***		
	(1.481)	(3.422)		
trade			0.209***	0.260***
			(5.256)	(7.108)
Latin America & Carribean		1.028*		0.919*
		(1.882)		(1.654)
Asia		1.094***		1.032**
		(2.618)		(2.420)
Sub-Saharan Africa		1.406		1.360
		(1.453)		(1.384)
Middle East & North Africa		1.572***		1.556***
		(3.852)		(3.733)
_cons	0.131	-0.792**	-1.049**	-2.108***
	(0.321)	(-1.999)	(-2.393)	(-5.404)
Number of observations	2,320	2,320	2,576	2,576
r2_o	0.237	0.320	0.222	0.316
r2_w	0.126	0.104	0.164	0.133
r2_b	0.252	0.327	0.235	0.317
chi2		25.280		16.320
Prob>chi2		0.000		0.000
note: *** p<0.01, ** p<0.05, * p<0.1				

Non-Hydro Power

	NH1 FE coef/t	NH1 RE coef/t	NH2 FE coef/t	NH2 RE coef/t
gdppc	2.949***	2.465***	2.507***	2.040***
	(12.409)	(14.967)	(10.293)	(12.717)
fdi	0.032	0.084***		
	(0.960)	(2.863)		
trade			1.035***	1.065***
			(6.575)	(8.038)
Latin America & Carribean		-3.106***		-2.933***
		(-3.993)		(-3.793)
Asia		-1.396**		-1.314**
		(-2.156)		(-2.038)
Middle East & North Africa		0.115		0.710
		(0.203)		(1.271)
_cons	-22.805***	-18.536***	-23.201***	-19.616***
	(-11.113)	(-13.582)	(-10.611)	(-16.096)
Number of observations	813	813	855	855
r2_o	0.042	0.126	0.040	0.154
r2_w	0.342	0.329	0.364	0.351
r2_b	0.064	0.203	0.045	0.217
chi2		33.710		8.610
Prob>chi2		0.000		0.014
note: *** p<0.01, ** p<0.05, * p<0.1				

Results II: Human Capital

RET

	RET3 FE coef/t	RET3 RE coef/t	RET4 FE coef/t	RET4 RE coef/t
gdppc	0.740***	0.762***	0.546***	0.593***
	(12.503)	(15.758)	(6.762)	(9.019)
enrollment	0.405***	0.450***		
	(5.507)	(6.474)		
completion			0.264***	0.392***
			(3.776)	(6.153)
Latin America & Carribean		0.724		0.690
		(1.397)		(1.257)
Asia		1.174***		1.259***
		(2.926)		(3.078)
Sub-Saharan Africa		1.398		1.436
		(1.528)		(1.548)
Middle East & North Africa		1.340***		1.490***
		(3.465)		(3.762)
_cons	-2.903***	-3.943***	-0.644	-2.292***
	(-4.892)	(-8.459)	(-0.906)	(-4.428)
Number of observations	2,234	2,234	1,585	1,585
r2_o	0.270	0.361	0.250	0.374
r2_w	0.174	0.140	0.135	0.100
r2_b	0.289	0.376	0.284	0.374
chi2		19.210		30.350
Prob>chi2		0.000		0.000
note: *** p<0.01, ** p<0.05, * p<0.1				

Non-Hydro Power

	NH3 FE coef/t	NH3 RE coef/t	NH4 FE coef/t	NH4 RE coef/t
gdppc	2.762***	2.523***	2.881***	2.286***
	(9.801)	(15.748)	(7.322)	(10.883)
enrollment	-0.072	0.106		
	(-0.153)	(0.253)		
completion			-0.751*	0.069
			(-1.922)	(0.237)
Latin America & Carribean		-3.168***		-2.924***
		(-4.097)		(-3.651)
Asia		-1.421**		-1.266*
		(-2.204)		(-1.893)
Middle East & North Africa		0.165		0.443
		(0.297)		(0.774)
_cons	-20.641***	-19.431***	-18.709***	-17.432***
	(-5.656)	(-9.132)	(-4.479)	(-10.469)
Number of observations	774	774	566	566
r2_o	0.044	0.135	0.058	0.178
r2_w	0.332	0.315	0.319	0.287
r2_b	0.066	0.223	0.081	0.266
chi2		12.350		34.450
Prob>chi2		0.002		0.000
note: *** p<0.01, ** p<0.05, * p<0.1				

Results III: Financial Development

RET

	RET5 FE coef/t	RET5 RE coef/t	RET6 FE coef/t	RET6 RE coef/t	RET7 FE coef/t	RET7 RE coef/t
gdppc	0.518***	0.689***	0.383***	0.658***	0.427***	0.647***
	(9.372)	(15.064)	(5.503)	(12.026)	(6.336)	(12.007)
assets	-0.003	-0.002				
	(-0.074)	(-0.069)				
liabilities			0.108***	0.067***		
			(4.680)	(2.846)		
credit					0.146***	0.129***
					(4.180)	(3.647)
Latin America & Carribean		0.803		1.233**		1.243**
		(1.470)		(2.252)		(2.217)
Asia		1.340***		1.069***		1.070***
		(3.225)		(2.687)		(2.625)
Sub-Saharan Africa		1.401		1.311		1.315
		(1.509)		(1.569)		(1.536)
Middle East & North Africa		1.524***		1.457***		1.481***
		(3.877)		(3.924)		(3.892)
_cons	0.774*	-1.382***	1.638***	-1.265***	1.082**	-1.435***
	(1.711)	(-3.539)	(2.969)	(-2.861)	(2.022)	(-3.332)
Number of observations	2,384	2,384	2,063	2,063	2,071	2,071
r2_o	0.273	0.357	0.224	0.378	0.233	0.379
r2_w	0.146	0.096	0.170	0.101	0.170	0.104
r2_b	0.265	0.361	0.218	0.357	0.224	0.353
chi2		0.100		96.800		38.760
Prob>chi2		0.950		0.000		0.000

note: *** p<0.01, ** p<0.05, * p<0.1

Results IV: Financial Development

Non-Hydro Power

	NH5 FE coef/t	NH5 RE coef/t	NH6 FE coef/t	NH6 RE coef/t	NH7 FE coef/t	NH7 RE coef/t
gdppc	2.721***	2.437***	2.878***	2.568***	2.877***	2.610***
	(10.253)	(14.861)	(8.828)	(14.383)	(8.889)	(14.406)
assets	0.295*	0.486***				
	(1.681)	(2.913)				
liabilities			-0.047	0.076		
			(-0.469)	(0.789)		
credit					-0.388***	-0.097
					(-2.935)	(-0.789)
Latin America & Carribean		-3.113***		-3.211***		-3.228***
		(-3.929)		(-3.418)		(-3.451)
Asia		-1.423**		-1.334*		-1.343*
		(-2.162)		(-1.920)		(-1.941)
Middle East & North Africa		0.295		0.094		0.013
		(0.518)		(0.160)		(0.022)
_cons	-21.925***	-20.409***	-21.847***	-19.697***	-20.540***	-19.400***
	(-9.190)	(-15.673)	(-7.793)	(-13.930)	(-7.255)	(-13.756)
Number of observations	824	824	752	752	754	754
r2_o	0.038	0.119	0.049	0.098	0.048	0.095
r2_w	0.335	0.323	0.322	0.308	0.314	0.299
r2_b	0.061	0.215	0.056	0.168	0.067	0.173
chi2		27.910		20.160		45.920
Prob>chi2		0.000		0.000		0.000
note: *** p<0.01, ** p<0.05, * p<0.1						

Results V: Regulation

	RET				
	RET8 FE	RET8 RE	RET9 RE	RET10 FE	RET10 RE
	coef/t	coef/t	coef/t	coef/t	coef/t
gdppc	0.679***	0.778***	0.716***	0.478***	0.441***
	(13.374)	(18.145)	(14.769)	(8.337)	(9.637)
feed-in tariff	-0.067	-0.054			
	(-1.092)	(-0.888)			
regulation (1st quartile)			0.324		
			(0.696)		
regulation (2nd quartile)			0.511		
			(1.035)		
regulation (3rd quartile)			0.552		
			(1.169)		
PM10 (1st quartile)				0.228***	0.212***
				(3.622)	(4.099)
PM10 (2nd quartile)				0.176***	0.168***
				(3.738)	(4.139)
PM10 (3rd quartile)				0.100***	0.100***
				(2.986)	(3.166)
Latin America & Carribean		0.847	1.608**		1.085*
		(1.543)	(2.486)		(1.819)
Asia		1.027**	0.978		1.193***
		(2.447)	(1.624)		(2.705)
Sub-Saharan Africa		1.358			1.713
		(1.397)			(1.391)
Middle East & North Africa		1.421***	2.277***		1.812***
		(3.465)	(4.422)		(4.203)
_cons	-0.535	-2.056***	-2.493***	0.896*	0.362
	(-1.283)	(-5.214)	(-3.788)	(1.904)	(0.876)
Number of observations	2,645	2,645	1,056	1,870	1,870
r2_o	0.240	0.325	0.568	0.216	0.305
r2_w	0.159	0.117	0.173	0.099	0.090
r2_b	0.245	0.329	0.605	0.241	0.310
chi2		19.510			3.620
Prob>chi2		0.000			0.460
note: *** p<0.01, ** p<0.05, * p<0.1					

Results VI: Regulation

Non-Hydro Power

	NH8 FE coef/t	NH8 RE coef/t	NH9 RE coef/t	NH10 FE coef/t	NH10 RE coef/t
gdppc	2.369***	2.256***	3.051***	2.760***	2.460***
	(9.616)	(14.172)	(17.256)	(9.162)	(13.078)
feed-in tariff	0.536***	0.756***			
	(3.377)	(5.076)			
regulation (1st quartile)			2.264***		
			(2.600)		
regulation (2nd quartile)			2.354***		
			(2.619)		
regulation (3rd quartile)			1.088		
			(1.317)		
PM10 (1st quartile)				-0.372	0.370
				(-1.412)	(1.635)
PM10 (2nd quartile)				-0.039	0.467**
				(-0.188)	(2.448)
PM10 (3rd quartile)				0.245*	0.499***
				(1.760)	(3.669)
Latin America & Carribean		-3.038***	-3.216**		-3.042***
		(-3.901)	(-2.475)		(-3.602)
Asia		-1.441**	-0.293		-1.210*
		(-2.221)	(-0.233)		(-1.709)
Middle East & North Africa		0.289	0.698		0.242
		(0.517)	(0.635)		(0.393)
_cons	-17.749***	-16.867***	-25.506***	-21.076***	-18.870***
	(-8.260)	(-12.755)	(-13.979)	(-8.053)	(-12.613)
Number of observations	872	872	704	654	654
r2_o	0.038	0.143	0.188	0.060	0.164
r2_w	0.335	0.313	0.323	0.378	0.358
r2_b	0.058	0.235	0.184	0.082	0.230
chi2		19.130			48.250
Prob>chi2		0.000			0.000
note: *** p<0.01, ** p<0.05, * p<0.1					

Results VIII

Sensitivity Analysis

Results X: Summary

- RET is positively and significantly associated with *LGDP*
- Non-hydro power is positively and significantly related to *LGDP*, *trade*, *assets* and *feed-in tariff*

Unexpected findings:

- Broadly based measures of *regulation* are not significant

Focus on Sub-Saharan Africa (SSA)

- 84% of countries within SSA produce electricity from renewables (main source: hydropower)
- Only 9 countries (Cape Verde, Cote d'Ivoire, Eritrea, Ethiopia, Gabon, Kenya, Senegal, South Africa, and Togo) produce renewable electricity from non-hydro sources

➔ Identified drivers of renewable energy adoption seem to be relevant with regard to RET in general, but not for non-hydro sources in SSA

Conclusions

- First cross-country analysis regarding the determinants of RET adoption in developing countries
- Generall assessment of various factors influencing the adoption of RET
- Highlights the sensitivity of various explanatory variables
  ➔ Identifies a need for further analysis